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**UTILITY
PATENT APPLICATION
TRANSMITTAL**

(Only for new nonprovisional applications under 37 C.F.R. § 1.53(b))

AF Inv D00378

Joseph M. Bennett

Mitigating Ignition of Fluids by Hot Surfaces

Express Mail Label No.

See MPEP chapter 600 concerning utility patent application contents

Assistant Commissioner for Patents
Box Patent Application
Washington, DC 20231

6. ☐ Microfiche Computer Program (*Appendix*)
7. ☐ Nucleotide and/or Amino Acid Sequence Submission (*if applicable, all necessary*)
- a. ☐ Computer readable copy
- b. ☐ Paper Copy (identical to computer copy)
- c. ☐ Statement verifying identity of above copies

- Descriptive title of the invention
- Cross References to Related Applications
- Statement Regarding Fed sponsored R&D
- Reference to Microfiche Appendix
- Background of the Invention
- Brief Summary of the Invention
- Brief Description of the Drawings (*if filed*)
- Detailed Description
- Claim(s)
- Abstract of the Disclosure

4. Oath or Declaration [Total Pages 1]

- a. ☒ Newly executed (original or copy)
- b. ☐ Copy from a prior application (37 C.F.R. §1.63(d))
for continuation/divisional with Box 17 completed
(Note Box 5 below)

- i. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application, see 37 C.F.R. §§ 1.63(d)(2) and 1.33(b)

5. Incorporation By Reference (usable if Box 4b is checked)

The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under Box 4B, is considered to be a part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

8. ☐ Assignment Papers (cover sheet & document(s))

9. ☐ 37 C.F.R. §3.73(b) Statement ☐ Power of Attorney
(when there is an assignee)

10. ☐ English Translation Document (if applicable)

11. ☒ Info Discl Stmt / PTO 1449 ☒ Copies of IDS Citations

12. ☐ Preliminary Amendment

13. ☒ Return Receipt Postcard (MPEP 503) (*,should be itemized*)

14. ☐ *Small Entity Statement(s) ☐ Filed in prior application, Status
(PTO/SB/09-12) still proper and desired

15. ☐ Certified copy of Priority Document(s) (*if foreign priority claimed*)

16. ☐ Other:

***NOTE FOR ITEMS 1 & 14: IN ORDER TO BE ENTITLED TO PAY SMALL ENTITY FEES, A SMALL ENTITY STATEMENT IS REQUIRED (37 C.F.R. §1.27), EXCEPT IF ONE FILED IN A PRIOR APPLICATION IS RELIED UPON (37 C.F.R. §1.28)**

17. If a **CONTINUING APPLICATION**, check appropriate box, and supply the requisite information below and in a preliminary amendment:

- ☐ Continuation ☐ Divisional ☐ Continuation in Part (CIP) of prior application No: _____

Prior application information: Examiner: _____ Group / Art Unit: _____

CORRESPONDENCE ADDRESS

- ☐
- Customer Number or Bar Code Label

(Insert Customer No. or Attach bar code label here)

- or ☒ Correspondence address below.

Name	Bobby D. Searce
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Name (Print / Type)

Bobby D. Searce

Registration No. (Attorney / Agent)

26333

Signature

Date _____

12 SEP 2000

FEE TRANSMITTAL for FY 2000

Patent fees are subject to annual revision.
Small Entity payments must be supported by a small entity statement,
otherwise large entity fees must be paid. See Forms PTO/SB/09-12.

Complete if Known

Application Number

Filing Date

First Named Inventor

Joseph M. Bennett

Examiner Name

Group Art Unit

TOTAL AMOUNT OF PAYMENT

(\$) 690.00

Attorney Docket Number

AF Inv D378

METHOD OF PAYMENT (check one)

FEE CALCULATION (continued)

1. ☒ The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

Deposit Account Number

AF 01-0465

Deposit Account Name

Department of the Air Force

- ☐ Charge Any Additional Fee Required under 37 CFR 1.16 and 1.17

2. ☐ Payment Enclosed:

☐ Check ☐ Money Order ☐ Other

FEE CALCULATION

1. BASIC FILING FEE

Lge Entity Fee Code	Lge Entity Fee (\$)	Sm. Entity Fee Code	Sm. Entity Fee (\$)	Fee Description	Fee Paid
101	690	201	345	Utility Filing Fee	\$690
106	310	206	155	Design Filing Fee	
107	480	207	240	Plant Filing Fee	
108	690	208	345	Reissue Filing Fee	
114	150	214	75	Provisional Filing Fee	

SUBTOTAL (1)

(\$) 690.00

2. EXTRA CLAIM FEES

Total Claims	Extra	Fee from below	Fee Paid
5 - 25** =	0	18	0
Independent claims	2 - 3 =	0	0
Multiple dependent claims			0

** or number previously paid, if greater, For Reissues, see below

Large Entity Fee Code	Large Entity Fee (\$)	Small Entity Fee Code	Small Entity Fee (\$)	Fee Description
103	18	203	9	Claims in excess of 20
102	78	202	39	Independent claims in excess of 3
104	260	204	130	Multiple dependent claim
109	78	209	39	**Reissue independent claims over original patent
110	18	210	9	**Reissue claims in excess of 20 and over original patent

SUBTOTAL (2)

\$ -0-

3. ADDITIONAL FEES

Large Entity Code	Large Entity Fee (\$)	Small Entity Code	Small Entity Fee (\$)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920*	112	920*	Requesting publication of SIR prior to Examiner Action	
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for response within first month	
116	380	216	190	Extension for response within second month	
117	870	217	435	Extension for response within third month	
118	1,360	218	680	Extension for response within fourth month	
119	300	219	150	Notice of Appeal	
120	300	220	150	Filing a brief in support of an appeal	
121	260	221	130	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive unavoidably abandoned application	
141	1,210	241	605	Petition to revive unintentionally abandoned application	
142	1,210	242	605	Utility issue fee (or reissue)	
143	430	243	215	Design issue fee	
144	580	244	290	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Statement	
581	40	581	40	Recording each patent assignment per property	
146	760	246	380	Filing a submission after final rejection (37 CFR §1.129(a))	
149	760	249	380	For each additional invention to be examined (37 CFR §1.129(b))	
Other fee (specify)					
Other fee (specify)					

SUBTOTAL (3)

\$

*Reduced by Basic Filing Fee Paid

SUBMITTED BY

Complete (if applicable)

Typed or Printed Name

BOBBY D. SCEARCE

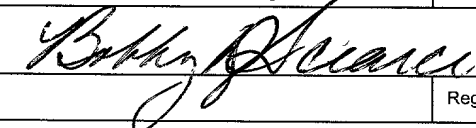
Registration No.

26333

Telephone

(937) 255-2838

Signature



Date

12 SEP 2000

Typed or Printed Name

Registration No.

Telephone

Signature

Date

MITIGATING IGNITION OF FLUIDS BY HOT SURFACES

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority of the filing date of Provisional Application Serial Number 60/220,226 filed 24 July 2000, the entire contents of which are incorporated by reference herein.

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RIGHTS OF THE GOVERNMENT

The invention described herein may be manufactured and used by or for the Government of the United States for all governmental purposes without the payment of any royalty.

BACKGROUND OF THE INVENTION

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The present invention relates generally to systems and methods for suppressing machinery fires, and more particularly to an economical, lightweight and reliable structure for mitigating the ignition of a flammable fluid leaked from the machinery onto a hot surface.

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Powered machinery may operate at very high exterior temperatures as a result of internal combustion or electrical power, grinding or machining operations, friction or other causes that characterize the operation. In particular, surfaces near the combustion region, exhaust manifolds, or bleed air/steam ducts of an operating engine can reach extremely high temperatures. Flammable fluids such as fuel, oil or hydraulic fluid in use near such surfaces leaking onto the hot surfaces and igniting has been documented as a frequent cause of fires near hot operating machinery, especially in automobiles. Aboard aircraft, a common cause of engine fires is the leakage of such fluids in the engine nacelle and subsequent ignition of the fluid by the hot engine core or uninsulated bleed air

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ducts. On-board fire extinguisher systems may be rendered ineffective if the fire is re-ignited by the hot surface after the extinguishant is depleted.

The invention solves or substantially reduces in critical importance problems in the prior art by providing a platform, housing, conduit, exhaust duct or other structural element that encloses or supports an engine (or other hot operating machinery) and which are heated in the course of engine operation, for mitigating ignition of flammable liquids that come into contact with such heated structure. A pattern of micro-cavities is defined on the outer surface of the structure and sized to minimize flammable liquid seepage into the cavities because of surface tension of the liquid, thereby preventing wetting of the interior of the cavities by the liquid. A gridwork of the cavities on the surface of the structure may provide 50% or more reduction of direct surface to liquid contact when the liquid spreads across the surface, which minimizes heat transfer to and vaporization and ignition of the liquid. The cavities also promote formation of nucleate bubbles at the onset of boiling that percolate harmlessly through the liquid, rather than form a superheated vapor film beneath the liquid that could seep from under the liquid pool, mix with air and ignite. The cavity pattern may be formed in the structure surface by machining, stamping, rolling, casting or other conventional process. The invention allows substantially hotter operating surface temperatures for the engine, or delays ignition of flammable liquids contacting the structure, and thereby allows a wider range of operating temperatures for the engine safe from the risk of fire. The invention adds no weight to the machinery, is highly reliable and adds no operating cost after initial fabrication.

The invention may be conveniently incorporated into bleed air ducts and engine surfaces of aircraft engines and auxiliary power units, military ground vehicle and ship engine or other machinery compartments, commercial vehicles, marine vessels, ground support and stationary power

engine or other machinery is described wherein a pattern of micro-cavities is defined on the outer surface of the structure for mitigating ignition of a flammable liquid that comes into contact with the structure, the micro-cavities being sized to minimize seepage into the cavities of the liquid because of its surface tension, thereby preventing wetting of the interior of the cavities by the liquid.

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DESCRIPTION OF THE DRAWINGS

The invention will be more clearly understood from the following detailed description of representative embodiments thereof read in conjunction with the accompanying drawings wherein:

FIG 1 is a schematic sectional view of a flammable liquid spreading over a heated surface;

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FIG 2 is a schematic sectional view of a flammable liquid spreading over a heated surface having micro-cavities formed in the surface according to a governing principle of the invention;

FIG 3 shows a schematic sectional view of a micro-cavity of the invention in a heated surface illustrating trapped vapor generated within the micro-cavity beneath the flammable liquid;

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FIG 4 shows a schematic sectional view of a micro-cavity of the invention in a heated surface illustrating percolation of vapor bubbles through the flammable liquid;

FIG 5 shows a schematic sectional view of a representative micro-cavity shape according to the invention; and

FIG 6 shows in section another representative micro-cavity shape according to the invention.

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DETAILED DESCRIPTION

Theoretical considerations and underlying principles of operation of the invention may be found by reference to "*Analysis of the Mechanisms of Pool Boiling and Ignition on Heated Surfaces*

and Proposed Mitigation Techniques," J. Michael Bennett, **UDR-TR-98-00159**, (August 1, 2000),
the entire teachings of which are incorporated by reference herein.

Referring now to the drawings, FIG 1 is a schematic sectional view of a pool of flammable
liquid 11 spreading over a heated surface 13 of a structural element 14. If the temperature of surface
5 13 exceeds the boiling point temperature of liquid 13, a thin vapor barrier 16 may form between
surface 13 and liquid 11 as a result of film boiling. The separation between surface 13 and liquid 11
has the beneficial effect of reducing direct conductive heat transfer from surface 13 to liquid 11,
which in turn limits liquid 11 evaporation at outer surface 17 and limits the mixing of sufficient
vapor with air to result in ignition. However, because vapor barrier 16 is adjacent heated surface 13,
10 superheating of barrier 16 results while it is entrapped under liquid 11 until the vapor migrates from
under liquid 11 at the leading edge 18 of the pool and there mixes with air and easily ignites at 19.
The pre-heated vapor requires a lower surface temperature (and resultant air temperature above at
the point of ignition) to successfully ignite.

In accordance with a governing principle of the invention, reduced conduction heat transfer
15 from the heated surface to the liquid due to techniques to minimize direct surface-to-liquid contact
area mitigates vaporization of a sufficient vapor concentration at the liquid's outer surface for
ignition, while preventing formation of a vapor film barrier that permits the superheating of the
vapor prior to mixing with air.

Referring now to FIG 2, shown therein is a schematic sectional view of a flammable liquid
20 21 spreading over a heated surface 23 having a pattern of micro-cavities 22 formed in surface 23
according to the invention. The width of each micro-cavity 22 is sized according to the surface
tension and resultant contact angles of liquid 21 to minimize seepage of liquid 21 into cavities 22.

cavity 22 would require minimum depth of about 0.433 mm, and a 0.25 mm diameter cavity would require a cavity 22 depth of about 0.217 mm. As a general proposition, acceptable cavity 22 sizes in contemplation of the invention fall in the range of up to a few millimeters in width or diameter and depth for most flammable liquids 21, the specific sizing of the cavity determined according to the viscosity of the contacting liquid.

Micro-cavities 22 may be distributed over any selected portion of heated surface 23, and may be impressed onto surface 23 by any suitable production process known in the applicable art, including forging, casting, rolling or automated machining process such as laser or hot electrode milling, the specific process selected for any particular application not considered limiting of the invention.

A principal feature of the invention is the minimization of heat transfer from hot surface 23 to flammable liquid 21 as a consequence of less than total liquid 21 to surface 23 contact resulting from a portion of the liquid 21 film being suspended over cavities 22, and heat transfer occurring only from vapor 26 within cavities 22, vapor 26 having substantially smaller heat conductivity than hot surface 23 of the structure. If a substantial portion of the surface 23 area contains cavities 22, a significant decrease in heat transfer from surface 23 to liquid 21 results, and a hotter surface 23 would be required to cause ignition, and a wider range of safe operating conditions for the structure results. For cavities 22 of very small diameter in a densely packed arrangement, a minimal quantity of liquid 21 will contact and be heated by the cavity walls.

Referring now to FIG 4, shown therein is a schematic sectional view of a micro-cavity 42 of the invention in a heated surface 43 illustrating another feature of the invention in the percolation of vapor 46 bubbles 47 through flammable liquid 41. Vapor 46 entrapped within cavity 42 is heated

by the hot cavity 42 walls, expands, pushes liquid 41 out of cavity 42 and forms a bubble at mouth 45 of cavity 42. When bubble 47 expands sufficiently to break free of cavity mouth 45, it percolates upward through liquid 41. The liquid 41 pool is generally sub-cooled (below boiling), and therefore cools bubbles 47 and harmlessly dissipates the heat within liquid 41. The repetitive formation and release of bubbles 47 is similar to nucleate boiling, and promotes the release of vapor 46 formed at the solid surface/liquid interface rather than the formation of a vapor film that has been identified as a means of sustained superheating of vapor which migrates to the liquid 41 pool edge and ignites.

Referring now to FIG 5, it is seen that the invention also contemplates micro-cavity shapes other than right circular cylinders or grooves oriented normal to the surface. Any shape for the micro-cavities would be acceptable as would occur to the skilled artisan practicing the invention so long as the surface tension of the contacting liquid substantially prevents seepage into the cavity. For example, cavity 52 may be machined or otherwise impressed onto surface 53 with the centerline of cavity 52 inclined at any selected angle to surface 53 in order to further minimize potential wetting of the cavity 52 walls by liquid 51, and the angle θ' illustrated in FIG 5 may correspond to the contact angle of liquid 51. Rectangular slots can also be added of fixed width and length, and if the expected point of initial liquid contact with the heated surface is known, a series of annular ring trenches can be impressed in the surface around that point to entrap vapor within each ring.

Referring now to FIG 6, a low cost method to manufacture the desired cavity features into the surface 63 of a structure 60 to be protected is suggested wherein a layer 64 of porous medium, such as thermally sprayed metals including steel, iron or others, is applied to surface 63 by powder metallurgy and sintering techniques well known in the applicable art, which may be precisely controlled to produce a distribution of pores of selectable diameter, within a tightly defined range of

variability. Once applied, the outer surface of layer 64 may be machined or polished to expose open pores in the form of cavities 62. Only a small portion of the cavity 62 outer surface is exposed, and such re-entrant cavities promote minimal seepage of liquid because of the extreme angle of the inner pore walls relative to the contact angle of liquid 61. Because cavities 62 are needed only on surface 5 63 exterior, a very thin porous section can be applied in a one-step process to the outer surface 63 of the structure to be protected, or the entire structure 60 may be fabricated in this manner.

Surface coatings can also be added in these processes to inhibit wicking and wetting of the pore or cavity walls. These coatings (such as TEFLON) effectively increase the contact angle between the liquid and the coating material (as opposed to the uncoated surface), which in turn 10 reduces the degree of liquid seepage and heating within the cavities.

Coatings may also be applied to fill the cavities with substances well known to those skilled in the art that have lower thermal conductivities than air to further reduce heat transfer to the liquid suspended over the cavities. These substances also inhibit any seepage of liquid and the associated additional heat transfer, but may inhibit the desired heat expelling capability of the structure (if such 15 is important) during normal operation. The substances could be spread over the surface and allowed to seep inside (possibly by the application of pressure), then wiped off the surface exterior to allow retention of the coating only within the cavity interiors. This process could be performed in an automated process by those skilled in the appropriate art. An example of such materials are the aerogel class of materials such as disclosed in U.S. Patent 6,068,882 by Ryu, the entire teachings of 20 which are incorporated by reference herein. Aerogels are an extremely porous and light form of glass (silica) formed in a special process to result in internal pores of nanometer scale. These materials have roughly a third of the conductivity of air (0.015 w/mK versus 0.055 w/mK for air at

I CLAIM:

1. A structural element for enclosing or supporting hot operating machinery, comprising:
 - (a) a structural member for enclosing or supporting a hot operating machinery; and
 - (b) means defining a plurality of micro-cavities on the outer surface of said structural member for mitigating ignition of a flammable liquid that comes into contact with said structural member, said micro-cavities being sized to minimize seepage of the liquid into said micro-cavities because of the surface tension of the liquid.
2. The structural element of claim 1 wherein said micro-cavities are in the form of holes of selected shape defined in the surface of said structural member.
3. The structural element of claim 1 wherein said micro-cavities are in the form of grooves defined in the surface of said structural member.
4. The structural element of claim 2 wherein the centerline of said holes is non-perpendicular to said surface of said structural member.
5. A structural element for enclosing or supporting hot operating machinery, comprising:
 - (a) a structural member for enclosing or supporting a hot operating machinery; and
 - (b) a porous sintered coating on said structural member defining a plurality of micro-cavities in the surface of said coating for mitigating ignition of a flammable liquid that comes into contact with said coating, said micro-cavities being sized to minimize seepage of the liquid into said micro-cavities because of the surface tension of the liquid.

Table 1. Demographic characteristics of the study population	
Age (years)	65.0 ± 1.5
Gender	
Male	50 (50.0%)
Female	50 (50.0%)
Education (years)	12.0 ± 1.0
Marital status	
Married	40 (80.0%)
Single	10 (20.0%)
Occupation	
Retired	40 (80.0%)
Unemployed	10 (20.0%)
Health status	
Good	40 (80.0%)
Poor	10 (20.0%)
Smoking status	
Smoker	10 (20.0%)
Non-smoker	40 (80.0%)
Alcohol consumption	
Drinker	10 (20.0%)
Non-drinker	40 (80.0%)
Comorbidities	
Hypertension	20 (40.0%)
Diabetes	10 (20.0%)
Cholesterol	10 (20.0%)
Arthritis	10 (20.0%)
Depression	10 (20.0%)
Other	10 (20.0%)

12

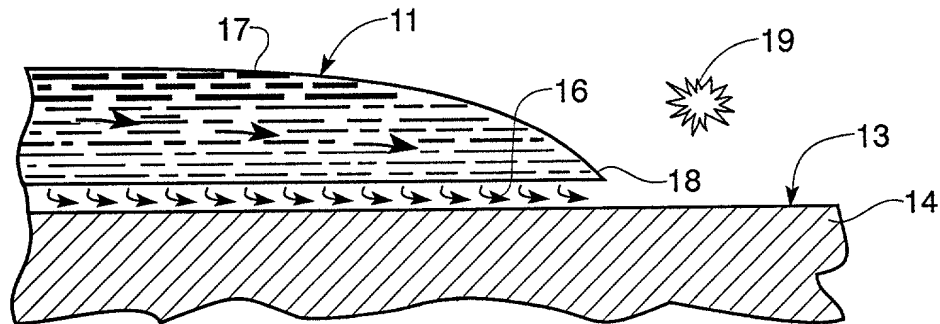


Fig. 1

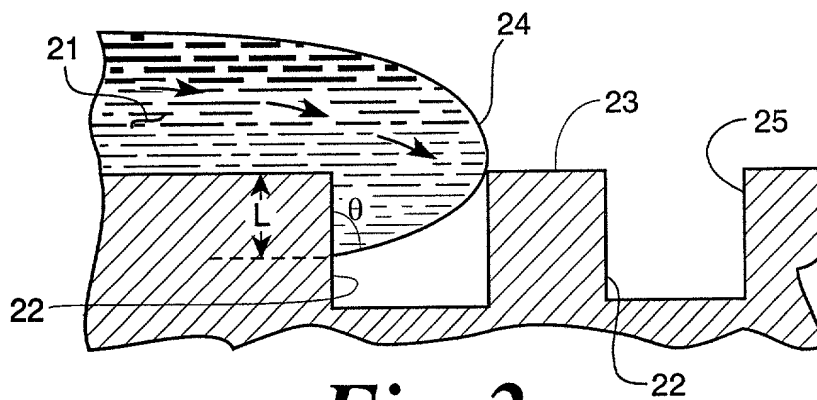


Fig. 2

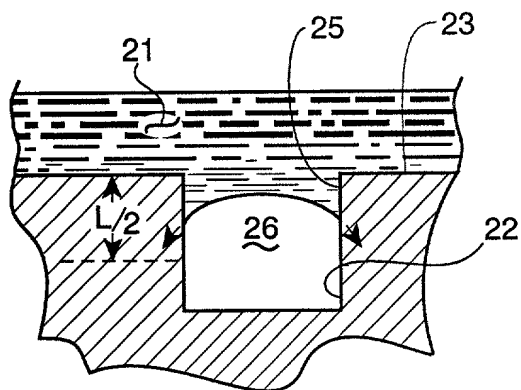


Fig. 3

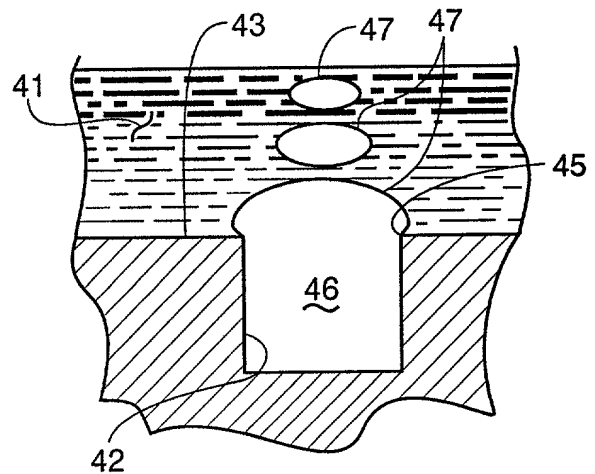


Fig. 4



DECLARATION FOR PATENT APPLICATION

Docket Number (Optional)

AF Inv D00378

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole (or joint) inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled MITIGATING IGNITION OF FLUIDS BY HOT SURFACES, the specification of which is attached hereto unless the following box is checked:

☐ was filed on _____ as United States Application Number or PCT International Number _____ and was amended on _____.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Priority Claimed

_____ (Application Number)	_____ Country	_____ (Day/Month/Year Filed)	<input type="checkbox"/> Yes <input type="checkbox"/> No
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_____ (Application Number)	_____ Country	_____ (Day/Month/Year Filed)	<input type="checkbox"/> Yes <input type="checkbox"/> No
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I hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

_____ (Application Number)	_____ (Filing Date)
-------------------------------	------------------------

_____ (Application Number)	_____ (Filing Date)
-------------------------------	------------------------

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

_____ (Application Number)	_____ (Filing Date)	_____ (Status - patented, pending, abandoned)
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_____ (Application Number)	_____ (Filing Date)	_____ (Status - patented, pending, abandoned)
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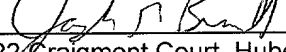
I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

Bobby D. Searce, Reg. No. 26,333 and Thomas L. Kundert, Reg. No. 27,247

Address all telephone calls to	Bobby D. Searce	at telephone number	(937) 255-2838
Address all correspondence to	AFMC LO/JAZ, Bldg 11		
	2240 B Street, Room 100		
	Wright-Patterson AFB OH 45433-7109		

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of sole or first inventor (given name, family name) Joseph M. Bennett

Inventor's signature	<u></u>	Date:	<u>11 Sept 2000</u>
Residence	<u>5722 Craigmont Court, Huber Heights OH 45424</u>	Citizenship	<u>U.S.A.</u>
Post Office Address	<u>Same as residence</u>		

☐ Additional inventors are being named on separately numbered sheets, attached hereto.